**Objective:** To provide an estimate of benefit, if any, of child restraint systems over seat belts alone for children aged from 2 through 6 years.

**Design:** Cohort study.

**Setting:** A sample of children in US passenger vehicle crashes was obtained from the National Highway Transportation Safety Administration by combining cases involving a fatality from the US Department of Transportation Fatality Analysis Reporting System with a probability sample of cases without a fatality from the National Automotive Sampling System.

**Participants:** Children in two-way crashes occurring between 1998 and 2003.

**Main Exposure:** Use of child restraint systems (rear-facing and forward-facing car seats, and shield and belt-positioning booster seats) vs seat belts. Potentially confounding variables included seating position, vehicle type, model year, driver and passenger ages, and driver survival status.

**Main Outcomes Measure:** Death of child passengers from injuries incurred during the crash.

**Results:** Compared with seat belts, child restraints, when not seriously misused (eg, unattached restraint, child restraint system harness not used, 2 children restrained with 1 seat belt) were associated with a 28% reduction in risk for death (relative risk, 0.72; 95% confidence interval, 0.54-0.97) in children aged 2 through 6 years after adjusting for seating position, vehicle type, model year, driver and passenger ages, and driver survival status. When including cases of serious misuse, the effectiveness estimate was slightly lower (21%) (relative risk, 0.79; 95% confidence interval, 0.59-1.05).

**Conclusion:** Based on these findings as well as previous epidemiological and biomechanical evidence for child restraint system effectiveness in reducing nonfatal injury risk, efforts should continue to promote use of child restraint systems through improved laws and with education and disbursement programs.

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survived because they were restrained in a child restraint system rather than a seat belt will not be included in the FARS database unless someone else in the crash died. This will lead to a potential underrepresentation of child restraint system use among surviving children and a consequent underestimation of the effectiveness of child restraint systems in reducing risk for fatal injury if only FARS data are used.

One method for dealing with selection bias inherent in a FARS-only analysis would be a matched case-control or double-sampling method that compares outcomes in children using different restraint types within a vehicle. Such analyses face limitations in this setting owing to small sample sizes, especially if other factors such as age or seating position are also matched for. We pursue an alternative analytical approach, that of combining the FARS database with the National Automotive Sampling System Crashworthiness Data System (NASS CDS), which includes a national probability sample of 2-way crashes. The NASS CDS provides a cross-section of crashes without regard to injury outcome but includes relatively few crashes with fatal child outcomes. By combining data from FARS and NASS CDS, we can obtain a sample of the entire cohort of children involved in 2-way crashes in the United States during a given period, with an identification of all of the fatally injured children during that time. Such analysis need not rely on assumptions about the representativeness of fatal crashes in the entire crash population.

Using sled tests, Kahane previously estimated a mortality risk reduction of 46% for children in child restraints compared with unrestrained children. Using the double-sampling method applied to FARS data, Partyka and Hertz found reductions of 47% to 59% in fatality risk for children aged 1 to 4 years in child restraint systems compared with unrestrained children. In more recent years, child restraint and seat belt use rates have increased dramatically. This study builds on the work of Kahane, Partyka, and Hertz by providing a current estimate of restraint effectiveness based on newer model year vehicles and restraints and by providing an estimate of the incremental benefit, if present, of child restraint systems over seat belts alone for young children.

DATA SOURCES

A census of children involved in crashes in the 50 states, the District of Columbia, and Puerto Rico, in which at least 1 passenger in 1 of the vehicles involved in the crash died, was obtained from the National Highway Traffic Safety Administration FARS database. To be included in FARS, a crash must involve a motor vehicle traveling on a traffic way customarily open to the public and result in the death of a person (occupant of a vehicle or a nonoccupant such as a pedestrian) within 30 days of the crash. We restricted our analyses to the 92% of vehicles that were nondrivable (could not be driven from the crash scene) for compatibility with the NASS CDS. Further, to focus on the effectiveness of current child restraint systems, only crashes between 1998 and 2003 were analyzed. A few crashes in which only nonoccupants died were also excluded. Because all US state laws require child restraints for children younger than 2 years but some states still allow seat belt restraints for children aged 2 years or older, this study was limited to children from the ages of 2 through 6 years. Within FARS, we identified 7813 children aged 2 through 6 years who were vehicle occupants restrained in a child restraint system or a seat belt in a nondrivable passenger car, van, pickup truck, or sport-utility vehicle that was involved in a crash with at least 1 passenger fatality between 1998 and 2003. Of these 7813 children involved in fatal crashes, 1096 children (14%) were killed.

A sample of children involved in nonfatal crashes was obtained from NASS CDS. The NASS CDS is a representative 3-stage probability sample selected annually from all police-reported crashes that resulted in at least 1 vehicle having to be towed from the scene because of damage. Approximately 5000 vehicle per year were sampled as part of the NASS CDS. Both vehicles in a NASS CDS-investigated crash were not necessarily nondrivable; therefore, we restricted our analyses to the 83% of vehicles that were nondrivable. Within NASS CDS, we identified 1433 children aged 2 through 6 years who were restrained in a child restraint system or seat belt in a passenger car, van, pickup truck, or sport-utility vehicle involved in a nonfatal crash sampled between 1998 and 2003. Because of the complex sample design of NASS CDS, these 1433 children represent 956820 children meeting our inclusion criteria.

VARIABLE DEFINITIONS

Our exposure variable of interest was child restraint system use vs seat belt use. Child restraint systems included rear-facing and forward-facing car seats, and shield and belt-positioning booster seats. Our primary analysis included all children 2 through 6 years old classified as either child restraint system or seat belt users, regardless of how the restraint was used. Our secondary analysis excluded the small fraction of children in FARS when the restraints were seriously misused. These included seat belt users who used a shoulder belt without a lap belt or improperly used the seat belt, for example, by restraining multiple children with a single seat belt, and also included child restraint users who did not attach the restraint to the vehicle seat or did not use the harness straps. Such misuse would usually be classified as nonuse in the NASS CDS; thus, a similar restriction was not necessary for the sample from NASS CDS. We also included driver, child, and vehicle characteristics of seating position (front seat vs rear seat), vehicle type (passenger car, pickup truck, van or minivan, and sport utility vehicle), model year (before 1990, 1990-1993, 1994-1997, after 1997), driver age (<20 years vs ≥20 years), passenger age (dummy variables for years 2-6), and driver survival status (as a marker of crash severity) as potential confounders. Direction of impact was not ascertained consistently in the 2 databases and was excluded from the analysis.

STATISTICAL ANALYSES

Bivariate analyses comparing fatalities and nonfatalities and restraint type with respect to crash characteristics (seating position, vehicle type, model year, driver and passenger ages, and driver survival status) were conducted. Robust χ² tests were performed to assess the differences in distributions in the bivariate analyses. Logistic regression modeling was used to compute the relative risk (RR) for death in children in child restraint systems vs seat belts. To estimate adjusted RRs, we used odds ratios from logistic regression; odds ratios will approximate RRs when the outcome is uncommon, as it was in this study. Because child restraint system users may differ from seat belt users in other crash characteristics, both unadjusted and adjusted analyses were conducted.
Because sampling in NASS CDS was based on model year and the severity of injury (including hospitalization status), subjects in less serious crashes were underrepresented in the study sample in a manner potentially associated with the predictors of interest. To account for this potential bias, case weights equal to the inverse of the probability of selection and adjusted to known crash totals were used to account for the oversampling of serious crashes in NASS CDS. (Case weights in FARS were set to 1, consistent with FARS being a census of all fatalities.) To adjust inference to account for the disproportional probability of selection of subjects and stratification and clustering of subjects by geographic region and vehicle, robust tests of association and Taylor series linearization estimates of the logistic regression parameter variances were calculated using SAS-callable SUDAAN: Software for the Statistical Analysis of Correlated Data, version 9.1 (Research Triangle Institute, Research Triangle Park, NC).

RESULTS

Data in the cohort (constructed as described earlier) included 9246 children, weighted to represent 964,633 children in nondrivable vehicles in crashes between 1998 and 2003. Table 1 gives the distribution of the variables used in the analysis, overall and by type of restraint used. Approximately 1 (0.11%) of 1000 children in a 2-way crash died. Somewhat fewer than half (45%) of all children were in child restraint systems, although younger children were much more likely to be restrained in child restraint systems. One (15.7%) of 6 children were in the front seat, two thirds (67.7%) were in passenger cars, one (15.6%) of 6 were in pre-1990 model year vehicles, and relatively few (4.0%) were driven by teenaged drivers; none of these factors were significantly associated with restraint type in bivariate analyses.

Table 2 summarizes little difference in the unadjusted risk for death between users of child restraint sys-
Child restraint systems offer a considerable safety advantage over seat belts alone for biomechanical reasons. Child restraint systems are designed to reduce risk for ejection during a crash, better distribute the load of the crash through structurally stronger bones rather than soft tissues, limit the crash forces experienced by the vehicle occupant by prolonging the time of deceleration, and potentially limit the contact of the occupant with intruding vehicle structures. Optimal performance of restraint systems depends on an adequate fit between the restraint system and the occupant at the time of the crash. Increased risk for injury in young children restrained in seat belts as a result of improper loading of deceleration forces has been documented for nearly 30 years.13,17 Child restraint systems offer improved fit of restraints for children who are too small for the adult-sized seat belt, thereby affording a mechanical protection advantage over seat belts. If restraint systems are seriously misused, however, their safety performance would be expected to be diminished. We adjusted for serious seat belt and child restraint system misuse (as defined in the “Methods” section) and found a slight increase in the relative effectiveness of child restraint systems compared with seat belts. In addition, previous in-depth analyses have demonstrated that most crashes in which children in child restraint systems die were of such severity that survival of the child was unlikely.10,17 Considering this, we included a variable for driver death (as a proxy for a potentially nonsurvivable crash) in our multivariate analyses.

Previous assessments of child restraint system effectiveness using nonfatal injury as an outcome have demonstrated the safety benefits of child restraint systems over seat belts alone for young children.2,3,17 The current study extends this evidence to include increased effectiveness of child restraint systems over seat belts alone in preventing death.

Our analysis was not without limitations. Restraint status information was missing for approximately 6% of children aged 2 through 6 years in the FARS data set and 9% of such children in the NASS CDS data set. Systematic differences between these subjects and those with restraint status provided may bias results, although the effect of such bias is likely to be small, given the relatively small amount of missing data. (Among restrained children aged 2 through 6 years, seating position was missing in 4% of restrained children aged 2 through 6 years in the FARS data set and 9% of children aged 2 through 6 years in the NASS CDS data set. Systematic differences between these subjects and those with restraint status provided may bias results, although the effect of such bias is likely to be small, given the relatively small amount of missing data. Therefore, to the extent that misclassification in restraint use exists in our sources of data, it is more likely that it may result in an underestimate of child restraint system effectiveness. Finally, while we have argued that using only the FARS data set puts one at risk for selection bias, use
of the NASS CDS to obtain a representative sample of the full two-way crash population may suffer from confounding between child restraint system use and crash severity, leading to either upward or downward bias in the estimate of child restraint system effectiveness. For example, if drivers who restrain their children in child restraint systems are less likely to be involved in potentially fatal crashes (ie, those fatal with the child in either a child restraint system or a seat belt, in a child restraint system only, or in a seat belt only), use of the NASS CDS population may overstate the effectiveness of child restraint systems vs seat belts by confounding child restraint use with safer driving behavior. The restriction of NASS CDS to two-way crashes and use of adjustment factors such as vehicle type, model year, age of driver, and, especially, survival status of the driver should reduce this confounding.

**IMPLICATIONS**

Our analysis, which considered key predictors other than restraint use that are associated with injury severity and addressed selection bias problems inherent in a FARS-only analysis by combing FARS and NASS CDS data into a single cohort, provides evidence that using child restraint systems rather than seat belts reduces mortality in children aged 2 through 6 years. Based on our current findings as well as the long-standing biomechanical evidence for child restraint effectiveness and previous demonstrations of the importance of child restraint systems in reducing nonfatal injury risk, efforts should continue to promote child restraint use through improved child restraint laws and with education and disinbursement programs. Further research is needed, however, to further refine restraint effectiveness estimation procedures and to ensure that the results are applicable to the current fleet, because this information is needed for evidence-based policy and product design.

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**REFERENCES**

Correction

Incorrect Terminology. In the article titled “Effectiveness of Child Safety Seats vs Seat Belts in Reducing Risk for Death in Children in Passenger Vehicle Crashes,” by Elliott et al published in the June issue of the ARCHIVES (2006;160:617-621) the term tow-away was incorrectly changed to the term two-way. Thus, on page 617, in the “Participants” subsection of the “Abstract,” the sentence should have read as follows: “Children in tow-away crashes occurring between 1998 and 2003.” The same error occurred on page 621, left-hand column, lines 1 and 2. These should have read “... of the NASS CDS to obtain a representative sample of the full tow-away crash population may suffer from confounding, ...” Further down on the same page and in the same column, the last sentence of that paragraph should have read as follows: “The restriction of NASS CDS to tow-away crashes and use of adjustment factors such as vehicle type, model year, age of driver, and, especially, survival status of the driver should reduce this confounding.”